Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 20 (2013) 290 – 297

Procedia Computer Science

Complex Adaptive Systems, Publication 3
Cihan H. Dagli, Editor in Chief
Conference Organized by Missouri University of Science and Technology
2013- Baltimore, MD

Research and Appliance of the Zero-Burden Based SoS Comprehensive Evaluation Method

Zhang Jing [a], Wang Mingyang [b], He Yan [a], Liu Zhiqiang [b], Li Wei [a]*

[a] *Science and Technology on Complex System Simulation Laboratory, Beijing Institution of System Engneering, Beijing, 100101, China*
[b] *PostBox 2857, 100085, Bejing, China*

Abstract

Current SoS (System of Systems) evaluation usually adopts the simulation techniques methods, which always need a mass of manpower, cost a long time, could hardly illustrated the structure information and domain knowledge inside SoS. So it couldn't satisfy the requirements of SoS comprehensive evaluation very well. To solve the problem above, a new method was prompted. Starting from the SoS concept and closely surrounding the SoS forming mechanism, this paper epurates a serious of factors which most impact the holistic level of SoS, further models the factors, the relationship between factors and the forming mechanism, then proposes a new SoS efficiency evaluation method. Different with other current SoS efficiency evaluation methods, this method not only integrates the domain knowledge, but also costs far less time than simulation, is nearly zero-burden. The requirements of SoS evaluation, such as great complexity, large sample, uncertainty and high performance computing, could be satisfied. Applications proved the rationality and validity of the zero-burden based SoS evaluation method.

Selection and peer-review under responsibility of Missouri University of Science and Technology

Keyword: System of Systems (SoS); Comprehensive Evaluation; SoS Simulation; Zero-Burden (0-B); Domain Knowledge

1. Introduction

System of Systems (SoS in short below) evaluation aims to support the ability evaluation, efficiency evaluation and architecture optimizing issues of SoS by analyzing and computing the global ability and compositive efficiency of SoS around various problems in SoS developing and building process which will be impacted by the composition, structure, quantity, exercise of SoS and many other factors.[1,2] For reason of great complexity, emergent property, hierachical property and uncertainty behavior of SoS, the traditional single system evaluate method is far from satisfying the requirement of SoS comprehensive evaluation. Then, premised on describing SoS effectually, a qualitative and quantitative combined analysis method, which considers all of the evaluation needs produced by SoS properties, should be introduced.

*Zhang Jing, Tel.: 86-13911703797; fax: 86-010-66356629.
E-mail address: zhangjing.benben@gmail.com .

Selection and peer-review under responsibility of Missouri University of Science and Technology
doi:10.1016/j.procs.2013.09.275

Currently, the common SoS evaluation methods can be primarily classified as charrette methods, analytic methods and simulation methods. [3] The first is qualitative and the last two are quantitative. Limited by the intellect and cognition to SoS of current human being and development of SoS technique, the above three methods still adopt a traditional reductionism idea which separates SoS to several isolated systems, evaluates them separately and gets a result by weighted calculating finally. Theoretically, these methods not only ignore the inside architecture information, but also lost the abundant domain knowledge contained in the SoS forming process. [4] Realistically, it would take a long time and huge manpower to execute the traditional method represented by simulation experiment. Because of the low flexibility and poor expansibility, the built simulation systems had to satisfy the diversification and quick response requirements. So, it urgently desires a new method which can fit the properties of SoS and satisfy the requirements of SoS evaluation to be employed in the practice of analyzing and optimizing neatly, quickly and easily.

Starting from the SoS concept and closely surrounding the SoS forming mechanism, this paper epurates a serious of factors which most impact the holistic level of SoS, further models the factors, the relationship between factors and the forming mechanism, then proposes a new SoS efficiency evaluation method. A real world application employs this method and validates this method. The practice shows that this method breaks through the reductionism idea, possesses the strongpoints of qualitative analysis among specialists, integrates the domain knowledge and the structure information of SoS. Especially, this method bases on an analytic computation approach, costs far less man power and time than simulation, is nearly zero-burden. The requirements of SoS evaluation, such as great complexity, large sample, uncertainty and high performance computing, can be satisfied.

The rest of this paper is organized in the following way. In Section 2, we discuss the basic issues in SoS evaluation. In Section 3, we explain the connotation of the zero-burden evaluation method. In Section 4, we introduce our new invented method. Then, a new implemented system based on this method is briefly presented and analyzed in Section 5. Finally, we conclude in section 6.

2. Basic Issues in SoS Evaluation

2.1. Characteristics and Requirements of SoS Evaluation

SoS is a high level system composed of several con-nected and interactional systems for reaching an appointed goal or accomplishing a given mission in an optimized structure under certain rudders. The acknowledged properties of SoS include emergent property, complexity, self- adaptability and uncertainty. It has become a research focus in system science and complexity research domain to discover the rules of how SoS works and evolves. Researching on SoS aims perfecting and optimizing SoS, improves the global capability. So, SoS evaluation is a basis for judging the SoS holistic level and concreting the effect of optimiz-ing SoS. It is one of the most important missions in SoS research domain.

SoS evaluation is mainly analyzing and calculating the global capability and compositive efficiency around various problems in SoS developing and building process. It is impacted by the composition, structure, quantity, exercise and so on factors. Considering the characteristics, SoS evaluation should satisfy the following requirements.

Request 1: Following the SoS forming mechanism which is that SoS integrates the influencing factors in every correlative domain, evolves, forms spontaneously and exists objectively. An evaluation method should effectively materialize its forming and executing mecha-nism.

Request 2: Answering for the requirements of great complexity property of SoS. An evaluation method should fully represent all the SoS concerned important factors, relationships and their effect to the holistic level of SoS.

Request 3: Answering for the requirements of the abstract and macro property of SoS. An evaluation method should not be immersed in analyzing the detail of SoS, but materialize the holistic and macro properties of evaluation point.

Request 4: Answering for the requirements of the uncertainty property of SoS. An evaluation method should deploy exhaustiveness or explorative analyzing job to deal with every conformation which SoS will represent.

Request 5: Answering for the requirements of the emergent of SoS. An evaluation method should fully integrate the domain knowledge inside SoS and realize qualitative analyzing and quantificational calculating.

In conclusion, evaluating SoS must satisfy the re-quirements of large sample, multi-sample, exploration, coarse granularity, super real time, intelligentize and the qualitative and quantitative combined analysis.

2.2. Forming Mechanism of SoS

Although SoS is described as a new aggregation com-posed by the relationships among systems in an intuitionistic way[4, 5], the formation of a SoS has preconditions and essential goals, evolves and develops through long time practice, comprehensively materializes the effect of users, can spontaneously forms a higher level and a stronger performance new system. Figure 1 illustrates the SoS forming mechanism. So, there must be plenty of domain knowledge inside each SoS. This is why SoS is deference with simple piling systems and represents emergent, uncertainty and so on properties essentially.

However, limited by the traditional system engineering and simulation methods, people now still mainly adopts reductionism idea which separates SoS into several single isolated systems. The structure information inside SoS is lost. The abundant domain knowledge inside SoS is lost. As a result, current SoS technics is hard to explain and analyze the problems such as emergent property and so on. It could even be said missing the essential problems which should be studied by SoS research. So, SoS evaluation must combine qualitative analysis and quantitative computing, combine micro analysis and macro integration, combine reductionism and holistic idea, combine science discursion and philosophy consideration and combine multi-subject theory, man joining ingredient and other influencing factors organically.

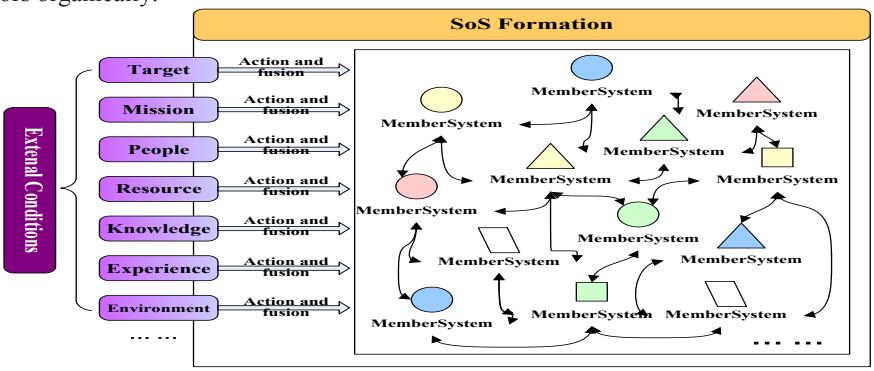

Fig. 1. SoS Forming Mechanism

2.3. Common SoS Evaluation Methods and Their Disadvantages

Currently, the common SoS evaluation methods can be primarily classified as charrette methods, analytic methods and simulation methods. The first is qualitative and the last two are quantitative. While SoS is being understood progressively and the complexity degree of SoS is increasing continually, people wants to illustrate the execution process and evolution process of SoS by a more intuitionistic way, and want to understand the essential properties of SoS in focus. Brain storm like charrette methods and analytical calculation methods all can't satisfy the requirements effectively any longer; meanwhile, simulation methods will be utilized more and more widely. [3]

A SoS simulation method will first build a computer program which can schedule every relational models, control the progress of simulation and get the concrete SoS executing instance under a predefined scenario based on modeling the SoS execution, the components execution, the interaction between SoS and its surrounded environment and so on problems. Then, the program can analyze the function of every SoS components and the capability and efficiency of SoS quantificationally. Especially, a well-designed simulation experiment will significantly improve the scientificalness and creditability of SoS research. Through SoS simulation method, the holistic level, contribute degree and sensitivity analysis problems of SoS have been well solved by comprehensively employing exploring analysis, multi-revolution modeling, complex network, Agent, network modeling of social behavior, aggregation and disaggregation modeling, value-center method and so on techniques. Meanwhile, a large

set of SoS simulation applications around world have been constructed, such as JCIM, RSAS, EADSIM, NSS, JWARS, SWARM, ExtendSim, Sim2000, CoSim and so on[2,6].

However, in real world applying, a majority of reductionism idea based SoS simulation programs can only model SoS components and their execution mechanism with a simple method. On the one hand, the interaction among the SoS components can hardly be effectually modeled, on the other hand, the domain knowledge inside SoS can hardly be materialized. As a result, now, SoS problems are still be solved by system simulation idea and techniques. Especially, while SoS is being understood progressively and the complexity degree of SoS is increasing continually, the development work for adjusting simulation system cost more and more and a timely response service can't be offered to every kind of SoS applications. So, SoS evaluation desires new approaches urgently.

3. Analysis of Zero-Burden Connotation

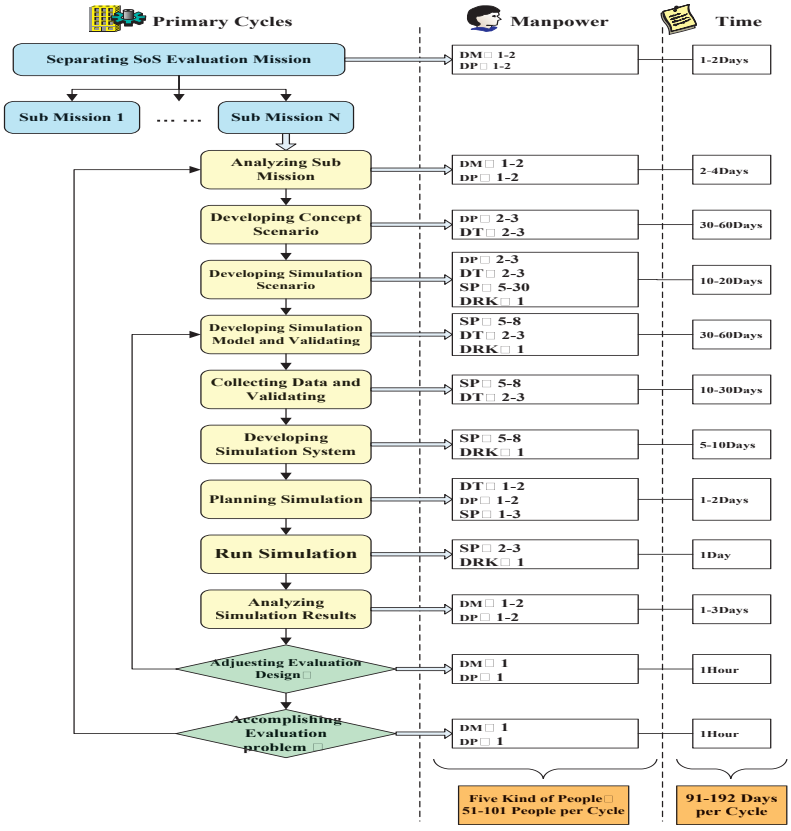

Fig. 2. SoS Simulation Primary Process and Cost

Starting from the SoS concept and closely surrounding the SoS forming mechanism, this paper proposes a new SoS efficiency evaluation method which can well satisfy great complexity, large sample, uncertainty and high performance computing requests. This method breaks through the reductionism idea, possesses the strongpoints of qualitative analysis among specialists, implements the integration of the domain knowledge and the structure information of SoS. Especially, this method bases on an analytic computation approach and called Zero-burden based SoS Comprehensive Evaluation Method (or ZBSoSCEM in short). The detail of ZBSoSCEM will be introduced in section 4. This section anatomizes the connotation of zero-burden first.

Zero-burden does not mean zero cost, but means that the workload can be nearly ignored when compares with SoS simulation methods. Figure 2 shows the man power and time required by the main processes of SoS simulation.

Usually, a SoS evaluation mission will be decomposed into several sub evaluation missions in the first stage. Based on analyzing these sub evaluation missions, the following work will be executed one by one: developing concept scenario and simulation scenario, the developing and verifying simulation model, collecting and verifying simulation data, developing simulation system, programming simulation experiment, executing simulation job, analyzing simulation results. 5 kinds of people (51 to 100 person time) coming from relational domains should attend these processes to-gether: decision-maker (DM), demonstrated pro-fessional (DP), domain theorist (DT), simulation profes-sional (SP) and device running keeper (DRK). For one sub evaluation mission, once execution will cost 91 to 192 days if no any adjusting and consummating is performed. It can be seen if all sub evaluation missions are accomplished by simulation experiment and performing the necessary adjusting and consummating during the experiment process, the manpower and time will be cost more.

Let's take a real world instance of SoS comprehen-sive efficiency evaluation mission which just finished by our group. This mission should evaluate the actual efficiency of an important SoS for future development. This SoS is divided into 6 components and designed according to the requirements of 4 typical background scenarios. Each scenario should take 48 hours and includes about 1700 entities. This SoS simulation system is developed by 12 units together and totally costs nearly 50 million RMB and 3 years. However, while this system should be adjusted on entity level, rule level and scenario level according to the re-quirements of real world applications, a mass of manpower and time should be cost either and can hardly deal with the complexity, diversification and uncertainty requirements of SoS.

4. Zero-Burden SoS Comprehensive Efficiency Evaluation Method

4.1. Primary Theory

ZBSoSCEM believes that SoS integrates the influencing factors in every correlative domain, evolves, forms spontaneously and exists objectively. The influencing factors for SoS are separated into inner-factors and outer-factors. As shown in Figure 3, the inner-factors include the systems which composing SoS and their relationships; meanwhile, the outer-factors include SoS requirements, boundary conditions, user groups and so on. These influencing factors not only have deferent functions to the holistic capability and efficiency of SoS independently, but also have complex interactions among each other. The abundant domain knowledge inside SoS can be regarded as held by domain specialists. So, ZBSoSCEM models and implements the above influencing factors and their correlations.

4.2. Key Problems

Based on the SoS Forming Mechanism, ZBSoSCEM suggests 11 most serious influencing factors. They are Knowledge & Experience (KE), Aim (A), Capability Index (C), Functional Characteristic (FC), Non-Functional Characteristic (NFC), Relationship between FC and NFC (RFC-NFC), System (S), System Function (SF), System Effectiveness (SE), System Cost (SC), System Quantity (SQ) and System Relationships (SR). The factors and the main influencing relationships among them are list below:

Knowledge & Experience (KE) denotes the relational experience, material, literatures and data. It helps the domain experts to learn the SoS characteristics and helps to configure a SoS instance.

Aim (A) denotes the target which should be achieved by SoS for finishing a certain mission. It guides people to analyze and build capability characteristics.

Capability Characteristic (C) denotes the concrete capabilities required for achieving the target of SoS. It helps to measure to what extent SoS reaching the expected target, e.g. safe execution ability and venture control ability of a high-speed rail SoS. If SoS have N_C concrete capability characteristics, C is a 1-dimention vector which includes N_C characteristics. Ci denotes the ith index.

Functional Characteristic (FC) denotes the concrete properties which support to achieve the target of SoS in the domain. It can be seen as the concrete representation in real world applications, e.g. expedite property, stability, controllability and expediency in a transport SoS. N_FC denotes the number of domain property indexes. Then FC is a 1-dimention vector which includes N_FC elements. FCj denotes the jth.

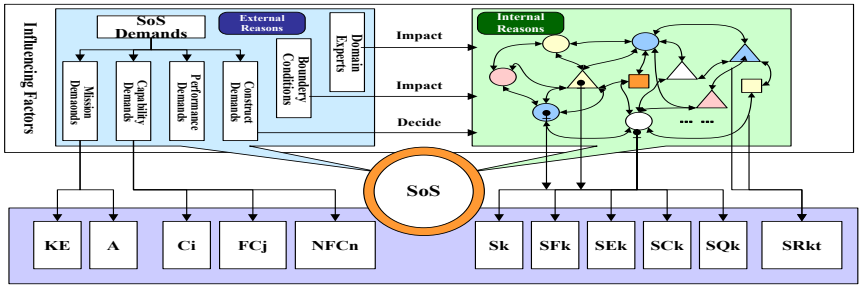

Fig. 3. Important Influencing Factors of SoS Formation

Non-Functional Characteristic (NFC) denotes the concrete properties which will impact the target of the SoS in relational domains. It can be seen as other domains act to current domain. e.g. maintenance cost, environment pollution and manufacture level in a transport SoS. N_NFC denotes the number of the characteristics of non-functional characteristics. Then NFC is a 1-dimention vector which includes N_NFC elements. NFCn denotes the nth.

Relationship between FC and NFC (RFC_NFC) denotes the interaction relationship of functional characteristic and non-functional characteristic. It will represent different form with deferent set of capability characteristics limitation. So, RFC_NFC denotes N_C N_FC × N_NFC matrixes. $R^{i}_{FC-NFC}(j, n)$ denote the jth functional characteristic acting to the nth non-functional characteristic.

Systems (S) denotes the systems in SoS. N_S denotes the number of member systems. S_k denotes the kth member system.

System Function (SF) denotes every member systems' function in SoS. It helps to support SoS to finish a certain mission or achieve a predefined target. SF_k denotes the main function of the kth member system.

System Efficiency (SE) denotes the capability or efficiency of every member systems. $SE \rightarrow FC$ denotes member systems contributing to functional characteristics, is a $N\_S \times N\_FC$ matrix. $N\_S_k \times N\_FC_j$ denotes the kth member system contributes to the jth functional characteristics. The same, $SE \rightarrow NFC$ denotes member systems contributing to non-functional characteristics, is a $N\_S \times N\_NFC$ matrix. $N\_S_k \times N\_NFC_n$ denotes the kth member system contributes to the nth non-functional characteristics.

System Cost (SC) denotes the economic index of every member systems, is scaled by cost. SC_k denotes the cost of the kth member system.

System Quantity (SQ) denote the quantity of every member systems. SQ_k denotes the quantity of the kth member system

System Relationships (SR) denotes the interaction relationships between each two member systems and the function of information system in SoS. SR is a $N\_S \times N\_S$ matrix. SR_{kt} denotes the kth member system acting to the tth member system.

4.3. Calculating Methods

According to above definitions, the method for calculating C_i :

$$C_i = f(f^{j}_{FC}(FC_j), f^{n}_{NFC}(NFC_n), R_{FC-NFC}) \quad (1)$$

In which, $f^{j}_{FC}()$ denotes a contribution function of the jth functional characteristic contributing to capability characteristic. $f^{n}_{NFC}()$ denotes a contribution function of the nth non-functional characteristic contributing to capability characteristic. $FC = f_1(S, SF, SE, SC, SQ, SR)$ denotes a calculation function of member function acting to functional characteristic. $NFC = f_2(S, SF, SE, SC, SQ, SR)$ denotes a calculation function of member function acting to non-functional characteristic. In order to insure the coherency of the comprehensive evaluation computing, f , f_1 and f_2 are given by ZBSoSCEM . And the computation work executes at background. $f^{j}_{FC}()$ and $f^{n}_{NFC}()$ are chosen by domain specialist according to different property.

Meanwhile, in order to insure the functional characteristics and non-functional characteristics impacting the

capability in formula (1) can be calculated, ZBSoSCEM builds two unitary indexes: λ_{FC} and δ_{NFC}. For calculating SQ, the SoS functions, the current system functions, the scale of member functions which plays certain functions and so on factors are comprehensively considered and substituted into formula (1) together. Now, in order to verify ZBSoSCEM, we build simple calculating formula for every function. The relational parameters in these functions are limited in integer of 0 to 9. Finally, these parameters are determined by domain experts.

5. System Implement and Applying

5.1. Zero-Burden Based SoS Comprehensive Evaluation System Design

According to the principle of ZBSoSCEM, we have designed and implemented a Zero-burden based SoS Comprehensive Evaluation System (or ZBSoSCES in short). Its executing flow chart is given by Figure 4.

In order to help domain experts to understand the system design idea and grasp the usage methods, ZBSoSCES is designed according to the natural SoS demand analysis processes. ZBSoSCES provides a friendly user interface. In the UI, users fill and set parameters in a navigator window. While the parameters are filling, a comprehensive SoS evaluation calculation can be executed.

It should be noticed that, although users should setting quite a number of parameters when evaluates a SoS by using ZBSoSCES, and the number of parameters is determined by the complexity of SoS, the capability characteristics, the functional characteristics and the non-functional characteristics, on the one hand, these parameters are the basic information needed by SoS analyzing and be necessary to other methods too, on the other hand, data will be accumulated during using this system. While these data is enough abundant and its quality is verified, these data can be regarded as an authoritative data source, then, the workload for user to fill these parameters will be decreased significantly.

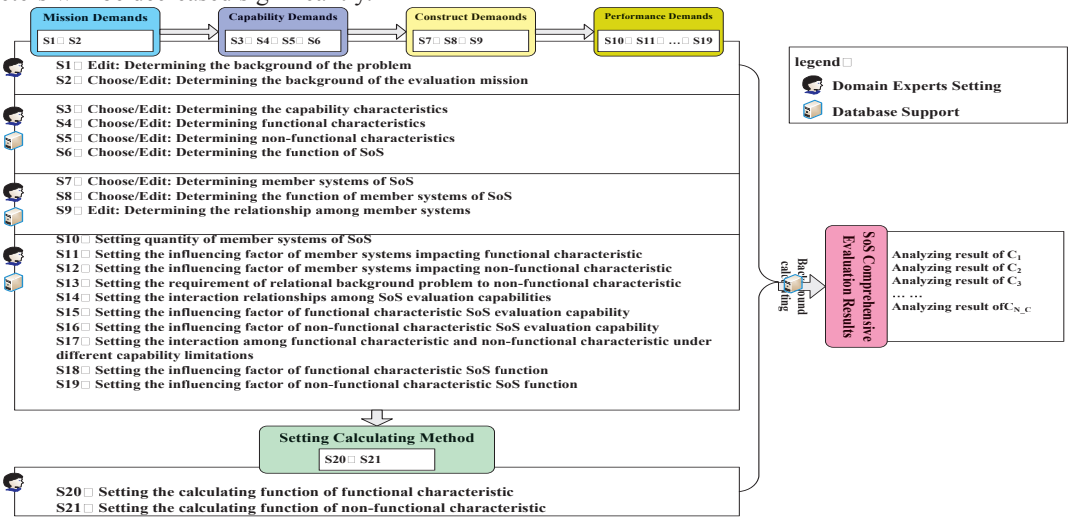

Fig. 4. ZBSoSCEM Based SoS Comprehensive Evaluation Process

5.2. System Implement

ZBSoSCES is implemented with a well-designed user interface and a wieldy operating method, is took the reference of key SoS simulation techniques. Figure 5 is a snapshot of ZBSoSCES UI. The S1 to S12 round button in this figure correspond to the S1 to S12 steps in Figure 4. As shown in the rectangle in the top and bottom of this figure, ZBSoSCES provides an operation navigator and a guage to help to use. Meanwhile, in order to let user to easily record his thought while in evaluation cycle, the system privates a situation-analyzing operation cycle in front

of the mission demands. It is as shown in the top-left rectangle in Figure 5. Domain experts can describe international situation, internal situation and domain situation in this cycle.

5.3. Workload Analysis for Using System

Using ZBSoSCES only need the attendance of decision-makers and demonstrate professionals who know domain problems, have no more developing workload. So, contracting with the cost of SoS simulation system as shown in Figure 2, a whole SoS evaluation work only need 1 to 2 decision-makers, 5 to 10 demonstrate professionals and 2 to 3 domain theorist to attend, and can only cost 3-6 days. It can be seen that, by using ZBSoSCEM, the manpower, time and money will be significantly reduced; the response of evaluation method will be quicker; the expendability will be better.

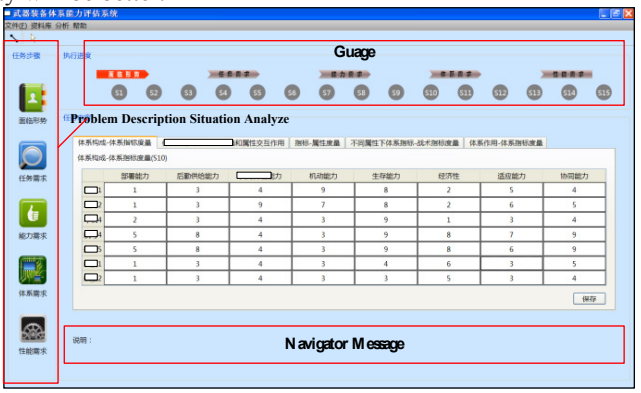

Fig. 5. UI of ZBSoSCES

6. Conclusions

Finally, it should be accented that, although this paper provides a comprehensive resolution way, which implicates an idea of qualitative analysis combining with quantitative analysis, for analyzing how domain knowledge and so on important factors impact SoS formation, it doesn't mean that SoS simulation methods could be replaced. ZBSoSCEM and the simulation methods should promote each other, support each other and verify each other. ZBSoSCEM more suit for solving strategic level problems, layout level problems and the problems which can hardly be simulated because of without any clear boundary conditions. It is a coarse granularity method. SoS simulation can provide a delicate granularity method for describing the evolution process of SoS, also has a wide domain and can support data for our method. So, which method should be chosen indeed should be flexibly decided by the end users, should according to the requirement of real world mission.

References

1. Mo Jamshidi. "System of Systems Engineering: Principles and Applications", Book. US: CRC Press, 2009.
2. Zhang Weiming, Liu Zhong et. al., "SoS Engineer-ing Theory and Methodology", Book, Science Press, 2010.
3. Hu Xiaohui, et.al. "Analysis Methods of Weapon Efficiency", Book, Defense Industry Press, 2008.
4. Zhang Zuiliang, et.al. "Science Road and Develop-ment Rules of SoS". Chinese Science Fund. 2006.3
5. Mark W.Maier. "Architecting Principles for system of systems". Journal, INCOSE. 1996, pp567-574
6. Zhang Jing, et.al., "Exploring Analysis Simulation Key Techniques for Complex System", Beijing, 2007
7. Zhang Jing, et.al., "Design and Realization of the Simulation Component based Parallel Framework for HLA Federate", SOSE 2012, 2012, P321-326